PATENT SPECIFICATION

(54) IMPROVEMENT IN OR RELATING TO PRODUCTION OF CRACKED GASES FROM LIQUID HYDROCARBON

(71) We, UBE INDUSTRIES, LTD., a Company organized and existing under the laws of Japan of 12—32, Nishihonmachi 1-chome, Ube-shi, Yamaguchi-ken, Japan, do hereby declare the invention for which we pray that a Patent may be granted to us and the method by which it is to be performed to be particularly described in and by the following statement:—

The present invention relates to a process for the preparation of gases such as olefins by thermal cracking of liquid hydrocarbons, particularly containing high boiling point constituents, such as crude oil, heavy oil and residue oil in a fluidized bed of solid particles, and further to a furnace for carrying out the cracking process. More particularly, the present invention relates to a process and a furnace for cracking not only a liquid hydrocarbon starting material in a specially designed fluidized bed of solid particles, but also the recovery of liquid hydrocarbon of higher boiling point containing carbon and tar in said bed at higher temperature. Said bed consists of an upper zone for quenching cracked gases, a central zone for cracking the starting liquid hydrocarbon and a lower zone for cracking the recovered liquid hydrocarbon which has originated in said bed wherein the solid particles are forced to circulate between said zones according to predetermined routes. The present invention has as its objective the provision of a process for cracking a starting liquid hydrocarbon starting material without exhausting the by-products produced by the cracking such as carbon and tar, heavy oil fraction and the like, which would ordinarily be treated as industrial wastes, and by utilizing said by-products improving the cracking efficiency and obviating such environmental pollution as occurs in the conventional process, and further, the provision of an improved cracking furnace for liquid hydrocarbon in a compact form which is suitably applicable to the process of the present invention.

There have been proposed many methods for producing olefins, hydrogen, fuel gas and the like by thermally cracking liquid hydrocarbon in a bed in which solid particles are fluidized. For instance, United States Patent No. 3238271 discloses a process for cracking liquid hydrocarbons to gaseous olefins by using two fluidized beds of solid particles which are formed within a cracking furnace and a regenerator separately. This process comprises: cracking the liquid hydrocarbon at a temperature of about 740°C in the cracking furnace by applying only the sensible heat of the fluidized solid particles delivered from the regenerator; passing the cracked gases into a cyclone without quenching them; washing the cracked gases by forcing them to flow counter to the liquid hydrocarbon containing higher boiling point constituents separated from the cracked gases by the process set forth below; removing the carbon deposited solid particles from the side wall of the cracking furnace and blowing them with air into the regenerator, thereby burning the carbon deposits with a part of the above-mentioned liquid hydrocarbon containing higher boiling point constituents at a temperature of about 900°C, which results in regenerating and heating the solid particles, and; passing the heated solid particles and steam stream from the regenerator into the cracking furnace at the bottom to crack the liquid hydrocarbon by the sensible heat of the solid particles as described below.

In the above prior art, only the sensible heat of the solid particles heated in the regenerator is applied as the heat source of the cracking reaction. Consequently, it is difficult to maintain the cracking furnace at such a high temperature as about 740°C. The supply of the heat to the cracking furnace necessary for cracking the liquid hydrocarbon requires transporting a large number of heated solid particles by steam. Passing the cracked gases directly from the cracking furnace into the cyclone without quenching them causes carbon

and tar to condense and deposit on the wall of the cyclone. This leads to a lower efficiency in capturing the carbon and tar with the result that a great amount of the carbon and tar is passed to the washing tower. Further, the liquid hydrocarbon containing higher boiling point constituents, which has been used for the countercurrent washing process at the time of regeneration of the carbon deposited particles, is treated by combustion only. As a result sulfur which is contained in the carbon material adhering to the solid particles is exhausted from the cracking system. In this connection, the prior art has a disadvantage in that prevention of the sulfur from exhausting to the atmosphere requires an additional process for desulfurization of the flue gas.

United Kingdom Patent No. 1,172,203, corresponding to U.S.P. No. 3551513, discloses a process for producing olefins at a high yield rate by partial oxidation of liquid hydrocarbon in a fluidized bed wherein a forced circulation flow of solid particles is employed. However, there is no suggestion of a possible treatment of the substances such as carbon, tar and heavy oil fraction which are by-produced by thermal cracking of the hydrocarbon.

The inventors thus have sought to realize a new method for thermally cracking liquid hydrocarbon in a fluidized bed of solid particles wherein by-produced carbon and tar heavy oil fraction and the like are utilized effectively and positively for the cracking purpose without exhausting the by-products from the cracking system, and as a result, they have confirmed that the following process avoids the disadvantages in the conventional cracking process and accomplishes the objectives of the present invention.

According to the present invention there is provided a process for thermally cracking a liquid hydrocarbon comprising forming a unitary fluidized bed of solid particles having a central zone for cracking a liquid hydrocarbon starting material to gases, an upper zone for quenching cracked gases and a lower zone for cracking liquid hydrocarbon recovered from the cracked gases, said central zone communicating with the upper and lower zones through narrow passages or neck zones formed therebetween; feeding oxygen, a first portion of steam as a fluidizing gas, a second portion of steam as a jet stream and a first portion of recovered liquid hydrocarbon into the lower zone from the bottom to fluidize the particles and partially burn the recovered liquid hydrocarbon thereby cracking the recovered liquid hydrocarbon to cracked gases; spraying a first portion of the liquid hydrocarbon starting material and feeding a third portion of steam as a fluidizing gas into the central zone while spouting steam, cracked gases and solid particles from the lower zone into the central zone thereby cracking the liquid hydrocarbon starting material to gases; spraying a second portion of the liquid hydrocarbon starting material and/or a second portion of the recovered liquid hydrocarbon into the upper zone while spouting the mixture of steam, cracked gases and solid particles from the central zone into the upper zone thereby quenching the gases and causing a part of the carbon, tar and heavy oil associated with the gases to adhere to the solid particles; removing the resultant gas mixture from the upper zone and separating the remaining tar, carbon and heavy oil therefrom which together constitute the recovered liquid hydrocarbon which is recycled to the process and returning contaminated solid particles from the upper zone to the lower zone.

Further the inventors have investigated the type of cracking furnace suitable for carrying out the above process and it is a further object of the invention to provide a furnace for carrying out said process.

The furnace of the present invention comprises three zones for forming a unitary fluidized bed, the said three zones being a central chamber for cracking liquid hydrocarbon starting material, a lower chamber for cracking recovered hydrocarbon and an upper chamber for quenching cracked gases, the central chamber and the upper chamber having constricted upper and lower portions respectively through which the upper and central chambers communicate, and the central and lower chambers having constricted lower and upper portions respectively through which the central and lower chambers communicate; said upper chamber being provided with an upper gas exhaust port, a solid particle outlet at an upper region of the chamber and an injection opening for liquid hydrocarbon at a lower region of the chamber; said central chamber having a first perforated conical plate gas distributor for a fluidizing gas forming the constricted lower portion of the central chamber, the gas distributor being provided with an injection opening for liquid hydrocarbon starting material; and said lower chamber having a second perforated conical plate gas distributor, forming a constricted lower portion of the lower chamber, for a first portion of steam as a fluidizing gas, the apex of which is adapted to issue a jet stream of a second portion of steam into the lower chamber and an injection nozzle for recovered liquid hydrocarbon being provided in the region of the apex, said lower chamber being further provided with a solid particle inlet connected to the solid particle outlet of the upper chamber for recycling solid particles.

According to the present invention, as the liquid hydrocarbon starting material any kind of liquid hydrocarbon can be used and in particular the cracking of liquid hydrocarbon

containing high boiling point constituents, such as crude oil, heavy oil and residue oil is easily attained. In this connection, the present invention is suitable for the production of fuel gas, hydrogen or olefins such as acetylene, ethylene and propylene, and particularly suitable for the production of fuel gas.

The first feature of the present invention is that the unitary fluidized bed used for cracking liquid hydrocarbon involves different function zones which are an upper zone for quenching the cracked gases, a central zone for cracking the liquid hydrocarbon starting material and a lower zone for cracking the recovered liquid hydrocarbon, the central zone communicating with the upper zone and the lower zone through the narrow neck passages formed between neighbouring zones, wherein solid particles are forced to fluidize throughout and not only cracking of the liquid hydrocarbon starting material but also further cracking of the recovered liquid hydrocarbon from the cracked liquid hydrocarbon starting material, which contains high boiling point constituents, are simultaneously carried out, while the cracked gases from the starting and recovered liquid hydrocarbon are quenched.

The second feature is that the sensible heat of the hot cracked gases from the recovered liquid hydrocarbon in the lower zone of the fluidized bed and the sensible heat of a part of the entrained solid particles of high temperature are applied for cracking the liquid hydrocarbon starting material.

The third feature of the present invention is that a part of the deposited carbon or contaminated solid particles is removed from the upper quenching zone and is forced to recycle to the lower cracking zone, whereby the deposits are utilized for improving the yield rate of the cracked gases and regeneration of the deposited carbon particles is attained. Further features of the invention will be apparent from the explanation below.

The invention will now be explained in detail by way of preferred embodiments with reference to the accompanying drawings in which:

Fig. 1 is a diagrammatic view showing the outline of an apparatus according to the present invention, and

Fig. 2 is a sectional view showing diagrammatically a cracking furnace for a liquid hydrocarbon according to the present invention.

With reference to Fig. 1, the apparatus comprises a cracking furnace for a liquid hydrocarbon (1), a cyclone for separating the effluent (2), a distillation column for cracked gases (3) and conduits or lines for passing the materials (4 to 17). The cracking furnace (1) comprises an upper chamber as a quenching chamber for cracked gases (1a), a central chamber as a cracking chamber for a starting liquid hydrocarbon (1b) and a lower chamber as a cracking chamber for recovered liquid hydocarbon (1c), the central chamber being connected to the upper and lower chambers by means of narrow necks or constrictions A and B respectively. In this furnace (1) solid particles are packed for forming fluidized beds.

Recovered liquid hydrocarbon is fed into the lower chamber (1c) at the bottom through the line (17) and further oxygen and steam are fed into chamber (1c) through the lines (4) and (5) respectively, thereby creating a partial combustion of the recovered liquid hydrocarbon for cracking to gases. Within the lower chamber (1c), a cracking zone of the recovered liquid hydrocarbon is then formed in the fluidized solid particles.

The cracked gases produced at a high temperature flow upwards with a part of the fluidized solid particles and they are spouted into the central chamber (1b) at the bottom through the lower narrow neck B, thereby forming a cracking zone of the liquid hydrocarbon starting material in the fluidized solid particles within the central cracking chamber (1b).

On the other hand, the starting liquid hydrocarbon, for example, crude oil, heavy oil, residue oil or the like is fed with steam in an atomized state into the central cracking chamber (1b), where the starting material is cracked to gases by the sensible heat of the cracked gases from the recovered liquid hydrocarbon and of the heated solid particles and/or the starting material is burned partially with oxygen which is supplied alternatively to crack the starting material to gases by utilizing its partial combustion, at a temperature of 700 to 900°C.

The cracked gases produced in the central chamber (1b) are mixed with the cracked gases from the lower chamber (1c) and the mixture is spouted into the upper chamber (1a) through the upper narrow neck A with a part of the fluidized solid particles, whereby a quenching zone for the cracked gases is formed within the upper chamber (1a).

The cracked gas mixture spouted at a temperature of 700 to 900°C is quenched to a temperature of about from 400 to 550°C by supplying to the upper chamber (1a) a recovered liquid hydrocarbon through the line (15) and/or a starting liquid hydrocarbon through a line (not shown) in an atomized state. At this time, a part of the carbon and tar and heavy oil contained in the cracked gases is adhered to the surfaces of the solid particles fluidized in the upper chamber (1a).

The cracked gas mixture is then taken out of the upper chamber (1a) through the line (9) to separate the residue of carbon and tar and heavy oil from the mixture, and the separated materials are then supplied to the lower

chamber (1c) where they are regarded as recovered liquid hydrocarbon.

For example, the cracked gas mixture is introduced through the line (9) to the cyclone (2), where carbon is separated and removed through the line (10). The purified mixture is then introduced through the line (11) to the distillation column (3), where the purified gas mixture is removed at the top through the line (12), while the heavy oil fraction containing tar is removed at the bottom through the line (14). The removed heavy oil fraction is used as recovered liquid hydrocarbon, and one part of it is introduced to the quenching chamber (1a) through the line (15) with the carbon from the line (10) either in a mixed state or in a separated state, while the other part is introduced to the lower cracking chamber (1c) through the line (16) with the carbon from the line (10) either in a mixed state or in a separated state. The line (13) provided in the distillation column (3) at the upper portion is used to force a light oil to circulate within the column. The light oil stems from a part of the heavy oil fraction from the line (14) and/or the purified gases from the line (12) by condensing them by means of a cooling process.

Turning to the solid particles which have been fluidized in the cracking furnace (1), in a process where a starting liquid hydrocarbon is to be cracked by utilizing the partial combustion of it, part of the solid particles in the lower chamber (1c) is conveyed to the next central chamber (1b), accompanied by the cracked gases from the recovered liquid hydrocarbon. The conveyed particles are then fluidized in the central chamber (1b) and a part of the solid particles accompanied by the cracked gas mixture from the starting and recovered liquid hydrocarbons is conveyed further to the upper chamber (1a). In the upper quenching chamber (1a), part of the carbon, tar and heavy oil in a condensed state adheres to the solid particles owing to the quenching of the gas mixture, whereby the solid particles are increasingly contaminated. Therefore, in order to burn the carbon, tar and heavy oil to gases and regenerate the solid particles, the contaminated solid particles are returned or recycled to the lower cracking chamber through the line (8). In other words, the solid particles, in this case, are normally recycled through the chambers in the sequence of, the recovered liquid hydrocarbon cracking chamber (1c) → the starting liquid hydrocarbon cracking chamber (1b) → the cracked gas quenching chamber (1a) → the recovered liquid hydrocarbon cracking chamber (1c).

Further in the case where the cracking of a starting liquid hydrocarbon is carried out by utilizing only the sensible heat of the cracked gases and the solid particles from the lower cracking chamber (1c), a by-pass route is provided by the line (7), in addition to the above-mentioned recycle system, from which a part of the solid particles in the central cracking chamber (1b) is normally removed through the side wall and is recycled to the lower cracking chamber (1c).

The recycling of the solid particles from the upper quenching chamber (1a) and the central cracking chamber (1b) to the lower cracking chamber (1c) is carried out by adjusting the number of circulating particles by means of an overflow system of valves provided in the lines (7) and (8).

Referring to Fig. 2, the cracking furnace 1 according to the present invention will be explained in more detail. The furnace (1) comprises an upper chamber for quenching cracked gases (1a), a central chamber for cracking a starting liquid hydrocarbon to the gases (1b) and a lower chamber for cracking recovered liquid hydrocarbon to gases (1c).

The upper chamber (1a) has a bottom of funnel form and is connected at the bottom to the central chamber (1b) at the top of an inverted funnel by means of the conduit-like narrow neck A, while the central chamber (1b) is connected at the bottom of a funnel to the lower chamber (1c) at the top of an inverted funnel by means of the conduit-like narrow neck B, whereby the furnace is formed as a unit for cracking the liquid hydrocarbon.

In the upper quenching chamber (1a), a gas exhaust port (18) at the top, an injection nozzle (20), having an opening (19) at the lower portion and a solid particle discharging conduit (22) having an outlet (21) at the upper side wall are provided. The injection opening for a liquid hydrocarbon (19) is preferably located at the bottom of the funnel as shown in the drawing. When the liquid hydrocarbon is spouted from the injection opening (19), steam with a liquid hydrocarbon starting material and/or recovered liquid hydrocarbon may be fed in a premixed state or an unmixed state. In the case of an unmixed state, the injection nozzle (20) is preferably of a two concentric pipes construction, the liquid hydrocarbon passing through the inner pipe, and the steam passing through the outer pipe.

The central cracking chamber for a starting liquid hydrocarbon (1b) is provided with a solid particle discharging conduit (24) having an outlet (23) at the upper side wall and a perforated plate gas distributor (25) which forms the bottom of a funnel, the perforated plate being connected to a conduit (26). In the conical perforated plate (25), one or more injection nozzles for feeding a liquid hydrocarbon starting material in an atomized state (28) through an injection opening (27) are provided. From the perforated plate (25), steam fed through the conduit (26) is distributed within the central cracking chamber

(1b) in order to maintain the solid particles in the starting liquid hydrocarbon cracking zone in a suitable fluidized state and to cause dispersion of the starting liquid hydrocarbon so that cracking of the starting material can be promoted. At this time, if a partial combustion of the starting material is utilized for cracking the material, oxygen is supplied from the perforated plate (25) together with the steam. However the oxygen is not required if the cracking of the liquid hydrocarbon starting material can be carried out completely by the sensible heat of the cracked gas and the solid particles spouted from the lower cracking chamber (1c) only.

When the liquid hydrocarbon starting material is fed from the injection opening (27) of the injection nozzle (28) in an atomized state, it may be injected with steam in a premixed state. Alternatively, the injection nozzle (28) of two concentric pipes construction may be used to feed the liquid hydrocarbon starting material through the inner piper and to feed the steam through the outer pipe. Furthermore three concentric pipes may be used to feed the steam through the outer the liquid hydrocarbon starting material is fed through the inner pipe, the steam is fed through the intermediate pipe and additional steam is fed through the outer pipe. This additional steam feeding improves the atomizing effect markedly.

The cracked gases from the starting liquid hydrocarbon in the central cracking chamber (1b) contain, as main components, ethylene, propylene, methane together with other components such as hydrogen, carbon monoxide, carbon dioxide, hydrogen sulfide, heavy and light oil fractions and carbon.

The lower chamber for cracking the recovered liquid hydrocarbon (1c) is provided at the bottom with a perforated plate of an inverted conical or funnel form as a gas distributor (29), the perforated plate being connected to a conduit (30). An injection conduit (32) with an opening for a gas jet stream (31) extends downwards from the lowermost part of the perforated plate (29).

Further an injection nozzle for feeding the recovered liquid hydrocarbon (34) is provided piercing the injection conduit (32) in an arrangement such that an injection opening (33) of the nozzle is located at the center of the gas jet stream opening (31). At the side wall of the lower chamber (1c), solid particle supplying conduits (36) and (38) are provided which have inlets (35) and (37) respectively. The inlet (35) of the lower chamber (1c) is connected with the outlet (23) of the central chamber (1b) through the conduit (36), line (7) and the conduit (24). This connection is intended to recycle the solid particles from the central chamber (1b) to the lower chamber as required thereby heating the solid particles so that the heated particles impart the heat to the starting liquid hydrocarbon sufficient for cracking the starting material to gases. The inlet (37) is connected with the outlet (21) of the upper quenching chamber (1a) through the conduit (38), line (8) and the conduit (22). This connection is intended to recycle the solid particles from the upper chamber (1a) to the lower chamber (1c), thereby regenerating the contaminated solid particles from the upper chamber (1a). From the inverted cone of the perforated plate (29), steam as a fluidizing gas for the solid particles is fed to the lower chamber (1c) along with oxygen which is applied for effecting partial combustion of the recovered liquid hydrocarbon and which may be pure oxygen or an oxygen-containing gas mixture, for example, air. From the gas jet stream opening (31) steam is injected as a jet stream at a higher linear velocity than that of the fluidizing gas fed from the inverted conical perforated plate (29). This operation ensures that a desirable fluidized bed where good dispersion of the solid particles takes place is maintained whereby cracking of the recovered liquid hydrocarbon is easily attained.

From the injection opening (33) of the nozzle (34). the recovered liquid hydrocarbon is sprayed together with steam. This injection nozzle (34) may be either a single pipe or a two concentric pipes construction as described before. In the lower chamber for cracking the recovered liquid hydrocarbon (1c), there are produced cracked gases containing *inter alia* hydrogen, methane, carbon monoxide carbon dioxide

With respect to the cracking furnace (1) according to the present invention, the bottom funnel of the upper quenching chamber (1a), the funnel type perforated plate (25) of the central cracking chamber (1b) and the bottom funnel of the lower cracking chamber (1c) are preferably of angles of from 60° to 120° respectively. Such design ensures the prevention of the solid particles from stagnating within the whole of the fluidized bed zones formed in the chambers (1a), (1b) and (1c), that is, avoids the phenomenon of stagnation of the solid particles in all of the bed zones, and maintains desirable fluidized bed zones.

The narrow necks A and B, that is, passages connecting the central chamber (1b) with the upper and lower chambers (1a) and (1c) may be designed so that the inside diameters of the necks are such that the gas velocities (U_n) (m/sec) therein are preferably in the range of from 1.1 to 4 times the linear terminal velocity of the solid particles U_t(m/sec) which is defined as follows.

$$U_t = \frac{g \cdot (\rho_a - \rho_g) \cdot d_p^2}{18\mu} \text{ at } R_{ep} < 0.4$$

$$U_t = \left[\frac{4(\rho_a - \rho_g)^2 \cdot g^2}{225\rho_g \cdot \mu}\right]^{\frac{1}{3}} \cdot d_p$$
$$\text{at } 0.4 \leqslant R_{ep} < 500$$

$$U_t = \left[\frac{3.1g \cdot (\rho_a - \rho_g) \cdot d_p}{\rho_g}\right]^{\frac{1}{2}}$$
$$\text{at } 500 \leqslant R_{ep} < 200{,}000$$

where

$$R_{ep} = \frac{\rho_g \cdot U_t \cdot d_p}{\mu}$$

g: acceleration of gravity (m/sec²)
ρ_a: particle density (kg/m³)
ρ_g: gas density (kg/m³)
d_p: particle size (m)
μ: gas viscosity
U_t: terminal velocity of the solid particles (m/sec)

The gas velocity (U_n) in the neck A or B is defined as follows.

$$U_n = (V_n/3600) \times \left(\frac{273 \times t_n}{273}\right) \times \left(\frac{1.033}{1.033 \times P_n}\right) \times \left(\frac{4}{\eta \, D_n^2}\right)$$

where
Vn ; volume rate of the whole gas passing through the neck A or B (Nm³hr)
t_n ; temperature of the gas at the neck A or B (°C)
P_n ; pressure of the gas at the neck A or B (kg/cm²G)
D_n ; diameter of the neck A or B (m)
U_n ; the gas velocity in the neck A or B (M/sec)

If a solid particle subjected to gravitational force is laid on the upper surface of a stationary fluid, the particle begins to fall in the fluid with a velocity increasing according to the lapse of time. Finally, the falling velocity of the particle reaches a constant value at the state that the gravitational force acting up-on the particle is balanced with the resistance force of the fluid acting upon the particle and the buoyancy of the particle exerted by the fluid. The above-mentioned velocity of constant value is referred to as a terminal velocity U_t.

In a case where the fluid flows with a constant velocity V in the direction opposite that of the gravitational force, the falling velocity of the particle is expressed by $U_t - V$. If the fluid velocity is not less than the terminal velocity U_t, the particle is ensured not to fall or drop in a stationary state. Therefore, by providing a fluid with a velocity relatively higher than U_t, the particle can not only be prevented from falling in the fluid but also can be forced to spout in the opposite direction of the gravitational force.

In this connection, the solid particles in the neck A or B are prevented from falling downwards through the neck under the condition that the gas velocity U_n in the neck A or B is in the range from 1.1 to 4 times the terminal velocity U_t. Further, the particles are forced to spout to provide a preferable distri-

bution of the particles in the fluid.

In general, the lengths of each neck preferably lies in the range of 0.2 to 0.4 times the height of the lower chamber (1c).

Nozzles for feeding liquid hydrocarbon to the quenching chamber, the central cracking chamber and the lower cracking chamber may be of a pressurized spray type.

Operational conditions of the cracking furnace according to the present invention will now be explained in detail.

To begin with, for the solid particles used in the present invention, any inert and refractory particles with sufficient mechanical strength, such as particles of refractory inorganic oxide such as alumina, silica, zirconia, titania, alumina-silica, silica-magnesia, silica-titania, alumina-magnesia, alumina-titania, cement clinker and mullite may be employed. Within the above materials, mullite particles are especially preferred.

The average diameter of the solid particles is preferably of the order of 0.5 to 5.0 mm, and the use of solid particles of the same size is desirable.

As for the number of the solid particles under forced circulation from the cracking zone for the liquid hydrocarbon starting material to the cracking zone for the recovered liquid hydrocarbon, it varies to some extent according to factors such as kinds of starting and recovered liquid hydrocarbons and cracking temperature, so that it is impossible to determine the number of circulating solid particles absolutely. However, in general the number circulating must be of an order sufficient to impart to the starting liquid hydrocarbon the sensible heat necessary for cracking the starting material.

Regarding the solid particles under forced circulation from the quenching zone for cracked gases to the cracking zone for recovered liquid hydrocarbon, although the

number varies in accordance with the extent of contamination of the solid particles and other factors, the amount circulated per hour is preferably 15% of all the solid particles.

In the present invention, U_{mf}/U_o is impor-

tant since it is used as an index indicating a fluidized state of the solid particles. U_o is identified as superficial velocity and is defined as follows.

$$U_o = (V_o/3600 \times (\frac{273 + t}{273}) \times (\frac{1.033}{1.033 + P}) \times (\frac{4}{\pi D_t^2})$$

where V_o is the volume rate of the whole gas passing through the upper, central or lower zone (Nm³/hr).

t is the temperature in the zone (°C).

P is the pressure in the zone (kg/cm³.G).

D_t is the diameter of the zone (m).

U_o is the superficial velocity of the whole

gas in the upper, central or lower zone (m/sec).

U_{mf} is identified as the minimum fluidizing velocity and is the gas velocity at the minimum fluidizing condition in the upper, central or lower zone. Such velocity is calculated from the following formula.

$$\frac{1.75}{\varphi_s \times (\varepsilon_{mf})^3} \times \frac{d_p.U_{mf}.\rho_g}{\mu} + \frac{150(1-\varepsilon_{mf})}{(\varphi_s)^2.(\varepsilon_{mf})^3} \frac{d_p.U_{mf}.\rho_g}{\mu}$$

$$= \frac{(d_p)^3.\rho_g.(\rho_s - \rho_g).g}{\mu^2}$$

where

g is the acceleration of gravity (m/sec²).

φ_s is the shape factor of solid particles.

d_p is the particle size (m).

ρ_s is the particle density (kg/m³).

ρ_g is the gas density (kg/m³).

μ is the gas viscosity in the upper, central or lower zone (kg/m.sec).

ε_{mf} is the voidage at minimum fluidizing condition.

U_{mf} is the minimum fluidizing velocity (m/sec).

Although the entire quantity of steam used as a fluidising gas and a gas jet stream in the cracking zone for a recovered liquid hydrocarbon depends on the physical properties of

the recovered liquid hydrocarbon, it is preferably in the range of 0.5 to 1.2 parts by weight per 1 part by weight of the amount of the recovered liquid hydrocarbon.

The gas velocity of the steam as a gas jet stream U_j (m/sec) (as later defined) may be preferably in the range of 2 to 10 times the superficial velocity (U_o) (m/sec) of the whole of the gas supplied to the cracking zone for recovered liquid hydrocarbon which is recalculated to the velocity at the pressure and temperature in the cracking zone.

The above mentioned gas velocity of the second portion of steam as a jet stream U_j (m/sec) is defined as follows.

$$U_j = (V_j/3600 \times (\frac{276 + t_j}{273}) \times (\frac{1.033}{1.033 + P_j}) + (\frac{4}{\pi D_j^2})$$

where

V_j is the volume rate of the steam injecting to the lower zone through the nozzle of the bottom of the lower zone (Nm³hr).

t_j is the temperature of the steam in the nozzle (°C).

P_j is the pressure of the steam in the nozzle (kg/cm².Co).

D_j is the diameter of the nozzle (m).

U_j is the gas velocity of the second portion of steam as a jet stream (m/sec).

The quantity of the steam may be preferably within the range of 10 to 30% by volume of

the whole amount of the gas supplied to the recovered liquid hydrocarbon cracking zone. The oxygen used as a part of the fluidizing gas must be the amount sufficient to burn the recovered liquid hydrocarbon partially at a desired temperature of 1050 to 1400°C thereby cracking the hydrocarbon to gases. Although the quantity of oxygen may vary according to the kind and quantity of the recovered liquid hydrogen, the cracking temperature, the temperature of the solid particles circulating under force and other factors, it may be generally in a suitable range of 0.5 to 2 parts by weight per 1 part by weight of the recovered liquid hydrocarbon.

The superficial velocity (U_o) (m/sec) of the whole gas in the cracking zone for a recovered liquid hydrocarbon must be of the order sufficient to maintain the fluidized state of the solid particles, and in general it may be varied within a preferable range of 1.3 to 6 times the minimum fluidizing velocity of the solid particles U_{mf} (m/sec).

By satisfying the above-mentioned conditions, there is attained the desired cracking in the lower cracking zone of the recovered liquid hydrocarbon consisting mainly of heavy oil fractions, carbon and tar and simultaneously it is possible to heat the solid particles from the central cracking zone for the starting liquid hydrocarbon and to regenerate the contaminated solid particles from the upper quenching zone for the cracked gases. In the above process, the gases produced by cracking the recovered liquid hydrocarbon in the lower cracking zone are forced to flow up to the central cracking zone together with a part of the solid particles through the narrow neck B.

In general, the quantity of the steam fed to the central cracking zone with the liquid hydrocarbon starting material is preferably in the range of 0.1 to 0.5 parts by weight per 1 part by weight of liquid hydrocarbon starting material.

The temperature of the central cracking zone for the starting liquid hydrocarbon should be maintained in the range of 700 to 900°C. For this purpose oxygen may be fed to effect a partial combustion of the starting liquid hydrocarbon as required thereby maintaining the central zone at the above temperature.

The average recalculated superficial velocity of the whole gas in the central zone U_o (m/sec) is preferably maintained in the range of 1.3 to 6 U_{mf}. The desired quantity the liquid hydrocarbon starting material and/or the recovered liquid hydrocarbon sprayed into the upper quenching zone for the cracked gases varies according to factors such as the temperature and quantity of the cracked gas mixture produced from the starting and recovered liquid hydrocarbons, so that it cannot be determined absolutely. In practice, it should be adjusted to an amount sufficient for quenching the cracked gases to a temperature of 400 to 550°C. If the quenching temperature is too low, that is, if the cracked gases are quenched to below 400°C, this causes agglomeration of the solid particles owing to adherence of tar contained in the cracked gas mixture and the sprayed recovered liquid hydrocarbon to the solid particles in large quantities. This agglomeration causes the fluidized state of the solid particles in the bed of the quenching zone and eventually in all of the fluidized bed zones to be degraded. On the other hand, if the quenched temperature is more than 550°C, a desirable quench-

ing effect of the cracked gas mixture cannot be obtained.

The average recalculated superficial velocity of the gas in the cracked gas quenching zone U_o (m/sec) is maintained preferably in the range of 1.3 to 4 U_{mf}.

With respect to the cracked gas mixture obtained by the above mentioned operations, carbon and tar, heavy oil fraction and other impurities may be separated from the gas mixture by a conventional process, for example, by a cyclone and then a distillation column. Further the resultant gas mixture may be refined to remove remaining impurities such as hydrogen sulfide and carbon dioxide by conventional processes.

According to the present invention, the recovered liquid hydrocarbon, which has been difficult to treat and thus has been a source of environmental pollution, can be cracked easily to gases without exhausting it from the system, and further its energy can be utilized for cracking a starting liquid hydrocarbon. In addition to the above, the present invention provides an advantage in that the cracking of the hydrocarbon, the quenching of the cracked gases and further the removal of a part of carbon and tar, heavy oil fraction can be carried out in a unitary fluidized bed or in a compact apparatus.

The refined gas according to the present invention is suitable as a fuel gas containing no sulfur. A town gas can be produced easily from the refined gas by adjusting the contents of hydrocarbons such as olefins, for example by catalytic hydrogenation with nickel.

The present invention is hereinafter explained in more detail by examples.

Example 1.

Liquid hydrocarbon was thermally cracked by employing a crack furnace 1 of the same type as shown in Fig. 2, wherein solid particles were fluidized.

The particulars of the furnace were as follows.

Height from the injection opening (31) at the bottom of the lower chamber (1c) or the cracking chamber for a recovered liquid hydrocarbon to the exhaust port (18) in the upper portion of the upper chamber (1a) or the cracked quenching chamber 8450 mm

The cracked gas quenching chamber (the upper chamber) (1a);

    Inside diameter 260 mmø (ø=diameter)
    Height 3300 mm

Inside diameters of the injection nozzle for a liquid hydrocarbon (19) of two concentric pipes construction (two nozzles of the same size were adopted)

    inner pipe 6.0 mmø
    outer pipe 9.3 mmø

Inside diameter of the solid particles outlet (21) 42 mmø

Angle of the funnel shoulder at the narrow neck A connecting the upper chamber (1a) with the central chamber (1b) 60°

Inside diameter of neck A 100 mmø

5 Height of neck A 400 mm

The cracking chamber for a starting liquid hydrocarbon (the central chamber (1b);

Inside diameter 200 mmø

Height 1920 mm

10 Angle of the funnel shoulder of the perforated plate (25) at the narrow neck B connecting the central chamber (1b) with the lower chamber (1c) 90°

Inside diameters of the injection opening

15 for a starting liquid hydrocarbon (27) of three concentric pipes construction (two openings of the same size were adopted)

inner pipe 3.0 mmø

central pipe 8.0 mmø

20 outer pipe 16.7 mmø

Inside diameter of the solid particle outlet (23) 76 mmø

Inside diameter of the narrow neck B 67 mmø

25 Height of neck B 700 mm

The cracking chamber for recovered liquid hydrocarbon (the lower chamber) (1c);

Inside diameter 130 mmø

Height 2100 mm

30 Inside diameter of the injection opening for a gas jet stream (31) 20 mmø

Inside diameter of the injection nozzle for a liquid hydrocarbon (34) 5.8 mmø

Inside diameter of the injection opening

35 (33) of the nozzle (34) 3.0 mmφ

Angle of the funnel shoulder of perforated plate (29) 90°

Inside diameters of the solid particle inlets (35) and (37) 76, 42 mmø

40 Residue-oil obtained from Khafji crude oil by normal atmospheric distillation with the following composition and properties was used as the liquid hydrocarbon starting material.

Specific gravity (d_4^{15}) 0.9572

45 Ash 0.029% w.t.

Sulfur 3.7% w.t.

C 84.8% w.t.

H 11.3% w.t.

In the above data, the entire quantity of C

50 and H (84.8% + 11.3%) includes asphaltene (4.9% w.t.) and Residue (10.5% w.t.)

As solid particles to be fluidized, particles of mullite having an average diameter of 3 mm in an amount of 130 kg were used.

55 The cracking operations adopted and the results obtained are as follows.

A recovered liquid, hydrocarbon separated from a cracked gas mixture, which will be described later at a feed rate of 39.8 kg/hr was atomized into the recovered liquid hydro- 60 carbon cracking chamber (1c) from the injection opening (33) along with super heated steam at 400°C at a feed rate of 4.8 kg/hr. Simultaneously another super heated steam at 400°C at a feed rate of 11.8 kg/hr was 65 injected into chamber (1c) from the injection opening (31) as a gas jet stream, while a gas mixture of super heated steam at 400°C at a feed rate of 17.7 kg/hr and oxygen at a feed rate of 45.6 Nm³/hr were fed into chamber 70 (1c) from the perforated plate (29) of funnel form. By the above operations, the recovered liquid hydrocarbon was burned partially and cracked to gases. At the same time, the cracked gas accompanied by a part of the solid par- 75 ticles was sprayed into the cracking chamber for the starting liquid hydrocarbon (1b), while steam at a feed rate of 9.0 kg/hr was supplied to chamber (1b) from the perforated plate (25) and starting liquid hydrocarbon at 80 a feed rate of 137.5 kg/hr was forced to flow into chamber (1b) from the two injection openings (27) in an atomized state along with super heated steam at 400°C at 19.3 kg/hr, whereby the starting liquid hydrocarbon was 85 cracked to gases at a temperature of about 850°C. Simultaneously solid particles at a rate of 770 kg/hr at 850°C were forced to circulate to the cracking chamber for the recovered liquid hydrocarbon (1c) from the 90 solid particle outlet (23) by the method of over-flowing. During the above operations, a recovered liquid hydrocarbon of 334 kg/hr was atomised into the cracked gas quenching chamber (1a) from the two injection nozzles 95 (19), accompanied by super heated steam at 12.6 kg/hr at 400°C, whereby the cracked gas mixture sprayed from the bottom of the upper quenching chamber (1a) was quenched to a temperature of about 500°C. Simul- 100 taneously the solid particles to which carbon, tar and heavy oil had adhered were forced to circulate at a rate of 41 kg/hr from the solid particle outlet (21) to the cracking chamber for the recovered liquid hydrocarbon (1c) 105 where they were regenerated for recycling. From the gas exhaust port (18) of the cracked gas quenching chamber (1a), a cracked gas mixture in a yield rate of 190 Nm³/hr (dry gases) was obtained. 110

Composition of the yielded gas mixture is shown in Table 1 below. The gas mixture contained heavy and light oils comprising carbon and tar in addition to the shown composition.

TABLE 1

Composition			Composition		
	(Vol. %)	(kg/hr)		(Vol. %)	(Kg/hr)
H_2	21.7	3.64	CO_2	12.4	45.64
CH_4	14.1	18.99	N_2	2.1	5.00
C_2H_2	0.9	2.01	H_2S	1.8	5.18
C_2H_4	15.1	35.38	Organic sulfur	0.06	0.15
C_2H_6	1.3	3.28	Benzene, Xylene and Toluene	1.9	12.19
C_3H_6	3.4	12.11			
C_3H_8	0.1	0.52			
C_4H_6	1.0	4.43			
C_4H_8	0.6	2.84			
CO	23.5	55.19			

The cracked gas mixture was then introduced into the cyclone (2), where carbon was separated out at a rate of 1.6 kg/hr and the remainder of the mixture was then fed to the distillation column (3), where a heavy oil fraction containing tar and light oil fractions was separated out at a rate of 38.2 kg/hr. The mixture of the separated carbon and the heavy oil fraction was fed as recovered liquid hydrocarbon in an atomized state from the injection opening (33) to the lower cracking chamber for the recovered liquid hydrocarbon (1c). The stored mixture of the carbon and the heavy oil fraction separated out by the cyclone and the distillation column was sprayed into the cracked gas quenching chamber (1a) for recycling at a feed rate of 334 kg/hr.

In the cracking zone for recovered liquid hydrocarbon within the lower chamber (1c), the average superficial velocity of the gas in the fluidized bed which was recalculated to the gas velocity at the temperature in the bed (U_o) was 8.0 m/sec, the linear velocity of the gas jet stream (steam) (U_j) was 30 m/sec, and the minimum fluidizing velocity of the solid particles (U_{mf}) was 1.7 m/sec. In the cracking zone for the starting liquid hydrocarbon within the central chamber (1b), the average recalculated superficial velocity of the gas in the fluidized bed (U_o) was 7.1 m/sec. In the quenching zone for the cracked gas in the upper chamber (1a), the average recalculated superficial velocity of the gas (U_o) in the fluidized bed was 3.7 m/sec. The linear velocity of the cracked gas from the recovered liquid hydrocarbon passing through the narrow neck B between the lower chamber (1c) and

the central chamber (1b) was 30 m/sec, while the linear velocity of the cracked gas mixture passing through the narrow neck A between the central chamber (1b) and the upper chamber (1a) was 28 m/sec.

With respect to the quantity of the solid particles retained in each chamber, that is a measure of the number of the solid particles remaining in each chamber, the respective quantities in the upper chamber (1a), the central chamber (1b) and the lower chamber (1c) were about 80 kg, 35 kg and 15 kg.

The recovered liquid hydrocarbon in an atomized state fed to the upper and lower chambers (1a) and (1c) had the following composition and properties:

Specific gravity (d_4^{15}) 1.2
Sulfur 7.3% w.t.
C 87.2% w.t.
H 5.1% w.t.

Example 2.

Liquid hydrocarbon was thermally cracked to gases by using the same furnace as in Example 1 under different conditions, wherein solid particles of a quantity of 130 kg were fluidized.

The solid particle outlet and inlet (23) and (35) were not provided.

Inside diameter of the narrow neck A connecting the upper chamber (1a) with the central chamber (1b) 146 mmø
Inside diameter of the central chamber (1b) 230 mmø
Inside diameters of the injection opening for the starting liquid hydrocarbon (27)

of three concentric pipes construction
inner pipe 3.0 mmø
intermediate pipe 6.3 mmø
outer pipe 21 mmø

5   Inside diameter of the injection opening
for the gas jet stream (31) 21 mmø

Inside diameter of the injection nozzle
for the liquid hydrocarbon (34) 6 mmø

Inside diameter of the injection opening
10   (33) of the nozzle (34) 3 mmø

As liquid hydrocarbon and solid particles,
the same materials as in Example 1 were employed respectively.

The cracking operations and the results are
15   as follows. A recovered liquid hydrocarbon
separated from a cracked gas mixture, which
will be explained hereafter, at a feed rate of
28.0 kg/hr was forced to flow into the recovered liquid hydrocarbon cracking chamber
20   (1c) in an atomised state from the injection
opening (33) along with super heated steam
at 400°C at a feed rate of 5.3 kg/hr. Simultaneously, super heated steam at 400°C at a
rate of 9.5 kg/hr was injected into chamber
25   (1c) from the injection opening (31) as a
gas jet stream, while a gas mixture of super
heated steam at 400°C at a rate of 14.2 kg/hr
and oxygen at a rate of 19.9 Nm³/hr was fed
to chamber (1c) from the perforated plate of
30   funnel form. By the above-mentioned operations, the recovered liquid hydrocarbon was
burned partially and cracked to gases. At the
same time, the cracked gas accompanied by a
part of the solid particles was sprayed into
35   the starting liquid hydrocarbon cracking

chamber (1b), while a gas mixture of steam
at a rate of 39.5 kg/hr and oxygen at a rate of
48.9 Nm³/hr was supplied to chamber (1b)
from the perforated plate (25) and the starting
liquid hydrocarbon at a rate of 184.7 kg/hr   40
was forced to flow into chamber (1b) from
the two injection openings (27) in an
atomized state along with super heated steam
at 400°C at a rate of 34.4 kg/hr, whereby the
starting liquid hydrocarbon was cracked to   45
gases at a temperature of about 850°C. A
circulating recovered liquid hydrocarbon at a
rate of 334 kg/hr was forced to flow into the
cracked gas quenching chamber (1a) in an
atomized state from the two injection openings (19) accompanied by super heated steam   50
at 400°C at a rate of 34.4 kg/hr whereby
the cracked gas mixture sprayed from
the bottom of the upper chamber (1a) was
quenched to a temperature of about 500°C.   55
Simultaneously, the solid particles to which
carbon tar and heavy oil had adhered were
taken out through the solid particle outlet (21)
and forced to circulate at a rate of 48 kg/hr
to the cracking chamber for the recovered   60
liquid hydrocarbon (1c) where they were regenerated for recycling.

From the gas exhaust port (18 of the
cracked gas quenching chamber (1a), a
cracked gas mixture of a yield rate of 242.8   65
Nm³/hr (dry gas) was obtained.

Composition of the yielded gas mixture is
shown in Table 2 below. The gas mixture contained heavy and light oils comprising carbon
and tar in addition to the composition shown.   70

TABLE 2

Composition			Composition		
	(Vol. %)	(kg/hr)		(Vol. %)	(kg/hr)
H_2	21.8	4.82	CO	20.1	61.97
CH_4	12.5	22.11	CO_2	21.3	103.46
C_2H_2	0.9	2.44	O_2	0.1	0.35
C_2H_4	12.9	39.94	N_2	1.6	4.82
C_2H_6	1.1	3.69	H_2S	1.8	6.69
C_3H_6	2.7	12.58	SO_2	0.1	0.81
C_3H_8	0.1	0.57	Organic sulfur	0.05	0.20
C_4H_6	0.8	4.99	Benzene Xylene and Toluene	1.5	13.08
C_4H_8	0.6	3.45			

The cracked gas mixture was then introduced into the cyclone (2), where carbon was
separated out at a rate of 2.7 kg/hr and the

remainder of the mixture was then fed to the   75
distillation column (3), where a heavy oil
fraction containing tar and a light oil fraction

of 16.7 kg/hr was separated out at a rate of 25.3 kg/hr.

The separated carbon and the separated heavy oil fraction were mixed and the mixture was sprayed into the recovered liquid hydrocarbon cracking chamber (1c) from the injection opening (33). The recovered liquid hydrocarbon was sprayed for recycling into the cracked gas quenching chamber (1a) from the injection opening (19).

In the cracking zone for recovered liquid hydrocarbon within the lower chamber (1c), the average superficial gas velocity in the fluidized bed, which was recalculated to the gas velocity at the temperature in the bed (U_o) was 8.0 m/sec, the linear velocity of the gas jet stream (steam) (U_j) was 30 m/sec, and the minimum fluidizing velocity of the solid particles (U_{mf}) was 1.7 m/sec. In the cracking zone for the starting liquid hydrocarbon within the central chamber (1b), the average recalculated superficial velocity in the fluidized bed of the gas (U_o) was 8.1 m/sec. In the quenching zone for the cracked gas within the upper chamber (1a), the average recalculated superficial velocity in the fluidized bed of the gas (U_o) was 4.6 m/sec. The linear velocity of the cracked gas from the recovered liquid hydrocarbon passing through the narrow neck B between the lower chamber (1c) and the central chamber (1b) was 20 m/sec, while the inner velocity of the cracked gas mixture passing through the narrow neck A between the central chamber (1b) and the upper chamber (1a) was 28 m/sec.

The recovered liquid hydrocarbon in an atomized state fed to the upper and lower chambers (1a) and (1c) had substantially the same composition and properties as that in Example 1.

WHAT WE CLAIM IS:—

1. A process for thermally cracking a liquid hydrocarbon comprising forming a unitary fluidised bed of solid particles having a central zone for cracking a liquid hydrocarbon starting material to gases, an upper zone for quenching cracked gases and a lower zone for cracking liquid hydrocarbon recovered from the cracked gases, said central zone communicating with the upper and lower zones through narrow passages or neck zones formed therebetween; feeding oxygen, a first portion of steam as a fluidising gas, a second portion of steam as a jet stream and a first portion of recovered liquid hydrocarbon into the lower zone from the bottom to fluidise the particles and partially burn the recovered liquid hydrocarbon thereby cracking the recovered liquid hydrocarbon to cracked gases; spraying a first portion of the liquid hydrocarbon starting material and feeding a third portion of steam as a fluidising gas into the central zone while spouting steam, cracked gases and solid particles from the lower zone into the central zone thereby cracking the liquid hydrocarbon starting material to gases; spraying a second portion of the liquid hydrocarbon starting material and/or a second portion of the recovered liquid hydrocarbon into the upper zone while spouting the mixture of steam, cracked gases and solid particles from the central zone into the upper zone thereby quenching the gases and causing a part of the carbon, tar and heavy oil associated with the gases to adhere to the solid particles; removing the resultant gas mixture from the upper zone and separating the remaining tar, carbon and heavy oil therefrom which together constitute the recovered liquid hydrocarbon which is recycled to the process and returning contaminated solid particles from the upper zone to the lower zone.

2. A process for cracking liquid hydrocarbon into gases according to claim 1, further comprising forcing some part of the solid particles in the central zone to recycle to the lower zone.

3. A process for cracking liquid hydrocarbon into gases, according to claim 1 or 2, further comprising feeding oxygen to the central zone to effect a partial combustion of the liquid hydrocarbon starting material, thereby cracking the starting material or promoting the cracking of the starting material.

4. A process for cracking liquid hydrocarbon according to any one of claims 1 to 3, wherein the gas mixture from the upper zone is separated by a cyclone into purified gases and carbon, and the purified gases are further separated by a distillation column into refined gases and heavy oil fraction and tar, said separated carbon, heavy oil fraction and tar being recycled to the fluidized bed as the recovered liquid hydrocarbon.

5. A process for cracking liquid hydrocarbon into gases according to any one of claims 1 to 4 wherein the partial combustion of the recovered liquid hydrocarbon in the lower zone is carried out at a temperature of 1050 to 1400°C, the thermal cracking of the liquid hydrocarbon starting material in the central zone takes place at a temperature of 700 to 900°C, and the cracked gas mixture is quenched in the upper zone to a temperature of 400 to 550°C.

6. A process for cracking liquid hydrocarbon into gases according to any one of claims 1 to 5, wherein the superficial velocity U_o (m/sec) (as herein defined) of the whole gas in the lower zone is adjusted within the range of 1.3 to 6.0 times the minimum fluidizing velocity of the solid particles U_{mf} (m/sec) (as herein defined) in the lower zone.

7. A process for cracking liquid hydrocarbon gases according to claim 6, wherein the superficial velocity (U_o (as herein defined) of the whole gas in the central zone is in the range

of 1.3 to 6.0 times the minimum fluidizing velocity U_{mf} (as herein defined) in the central zone.

8. A process for cracking liquid hydrocarbon according to claim 6 or 7, wherein the superficial velocity U_o (m/sec) (as herein defined) of the whole gas in the upper zone is in the range of 1.3 to 4.0 tmes the minimum fluidizing velocity U_{mf} (m/sec) (as herein defined) in the upper zone.

9. A process for cracking liquid carbon according to any one of claims 6 to 8, wherein the gas velocities U_n (m/sec) (as herein defined) in the narrow neck zones are in the range of 1.1 to 4 times the terminal velocity of the solid particles U_t (m/sec) (as herein defined).

10. A process for cracking liquid hydrocarbon into gases according to any one of claims 1 to 9, wherein the quantity of the first and second portions of steam used as a fluidizing gas in the lower zone is in the range of 0.5 to 1.2 parts by weight per 1 part by weight of the recovered liquid hydrocarbon sprayed into the lower zone and the quantity of the third portion of steam fed to the central zone is in the range of 0.1 to 0.5 parts by weight per 1 part by weight of the liquid hydrocarbon starting material feed.

11. A process for cracking liquid hydrocarbon into gases according to claim 10, wherein the quantity of oxygen supplied to the lower zone for effecting fluidization of the solid particles and a partial combustion of the recovered liquid hydrocarbon is in the range of 0.5 to 2 parts by weight per 1 part by weight of the recovered liquid hydrocarbon sprayed into the lower zone.

12. A process for cracking liquid hydrocarbon into gases according to any one of claims 6 to 11, wherein the gas velocity of the second portion of steam as a jet stream U_j (m/sec) (as herein defined) is adjusted within the range of 2 to 10 times the superficial velocity U_o (as herein defined) of the whole gas in the lower zone, and said steam is in the range of 10 to 30% by volume of the whole amount of the gas supplied to the lower zone.

13. A process for cracking liquid hydrocarbon into gases according to any one of claims 1 to 12, wherein the amount of contaminated solid particles under forced circulation from the upper zone to the lower zone in one hour is of the order of 15% of all the solid particles.

14. A process for cracking liquid hydrocarbon into gases according to any one of claims 1 to 13, wherein the solid particles used are inert and refractory particles with sufficient mechanical strength.

15. A process for cracking liquid hydrocarbon into gases according to any one of claims 1 to 14, wherein the solid particles used are of average diameter of the order of 0.5 to 5.0 mm.

16. A furnace for cracking liquid hydrocarbon comprising three zones for forming a unitary fluidized bed, the said three zones being a central chamber for cracking liquid hydrocarbon starting material, a lower chamber for cracking recovered hydrocarbon and an upper chamber for quenching cracked gases, the central chamber and the upper chamber having constricted upper and lower portions respectively through which the upper and central chambers communicate, and the central and lower chamber having constricted lower and upper portions respectively through which the central and lower chambers communicate; said upper chamber being provided with an upper gas exhaust port, a solid particle outlet at an upper region of the chamber and an injection opening for liquid hydrocarbon at a lower region of the chamber; said central chamber having a first perforated conical plate gas distributor for a fluidizing gas forming the constricted lower portion of the central chamber, the gas distributor being provided with an injection opening for liquid hydrocarbon starting material; and said lower chamber having a second perforated conical plate gas distributor, forming a constricted lower portion of the lower chamber, for a first portion of steam as a fluidizing gas, the apex of which is adapted to issue a jet stream of a second portion of steam into the lower chamber and an injection nozzle for recovered liquid hydrocarbon being provided in the region of the apex, said lower chamber being further provided with a solid particle inlet connected to the solid particle outlet of the upper chamber for recycling solid particles.

17. A furnace for cracking liquid hydrocarbon into gases according to claim 16, further comprising a passage between the central chamber and the lower chamber for recycling the solid particles.

18. A furnace for cracking liquid hydrocarbon into gases according to claims 16 or 17 wherein the constricted lower portions of the upper chamber is connected to the constricted upper portion of the central chamber by a narrow pipe, and the constricted lower portion of the central chamber is connected to the constricted upper portion of the lower chamber by another narrow pipe.

19. A furnace for cracking liquid hydrocarbon into gases according to claim 18, wherein each narrow pipe is of a height of 0.2 to 0.4 times the height of the lower chamber.

20. A furnace for cracking liquid hydrocarbon into gases according to any one of claims 16 to 19, wherein the constricted lower

portions of the upper, central and lower chambers are conical and have a conical angle from 60° to 120°.

21. A furnace for cracking liquid hydrocarbon into gases according to any one of claims 16 to 20, wherein the injection opening for the liquid hydrocarbon starting material at the conical portion of the central chamber is of a two concentric pipe construction, the inner pipe being used for feeding liquid hydrocarbon starting material and the outer pipe being for additional steam, as means for spraying the liquid hydrocarbon starting material.

22. A furnace for cracking liquid hydrocarbon into gases according to any one of claims 16 to 21, wherein the injection opening for the liquid hydrocarbon at the lower portion of the upper chamber is of a two concentric pipe construction, the central pipe being for recovered liquid hydrocarbon and/or liquid hydrocarbon starting material and the outer pipe being for additional steam as means for spraying the liquid hydrocarbon.

23. A furnace for cracking liquid hydrocarbon into gases according to any one of claims 16 to 22, wherein the injection nozzle at the apex of the second conical plate glass distributor of the lower chamber is of a two concentric pipe construction, the central pipe being for recovered liquid hydrocarbon and the outer pipe being for additional steam as means for spraying the recovered liquid hydrocarbon.

24. A furnace for cracking liquid hydrocarbon into gases according to any one of claims 16 to 23, wherein the first portion of steam and oxygen are fed from the second conical gas distributor of the lower chamber, while the third portion of steam is fed from the first conical gas distributor of the central chamber.

25. A furnace for cracking liquid hydrocarbon into gases according to claim 24, wherein oxygen is additionally fed from the first conical gas distributor of the central chamber.

26. A process for cracking liquid hydrocarbon substantially as hereinbefore described in the Examples.

27. A furnace for cracking liquid hydrocarbon substantially as hereinbefore described with reference to the accompanying drawings.

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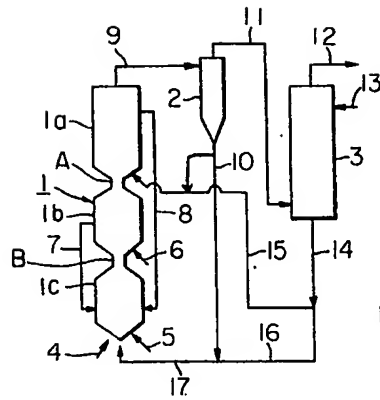Chartered Patent Agents,
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Fig. 1

Fig. 2